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RESEARCH PAPER

Effects of indigenous woody plantations on total nutrients of mine spoil in Singrauli Coalfield, India

A. N. Singh[1*], D. H. Zeng[2]

[1] *Department of Botany, Panjab University Chandigarh-160014, India*
[2] *Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China*

Abstract: A study was conducted on high-density young plantations of three native trees (*Albizia lebbeck*, *Albizia. procera* and *Tectona grandis*) and one native woody grass species (*Dendrocalamus strictus*) to examine their influence on total nutrient concentrations of coal mine spoil during early phase of plantation establishment. Soil samples were analyzed for total organic carbon (SOC), Kjeldahl nitrogen (TKN) and phosphorus (TP) at spoil depths of 0–10 and 10–20 cm under 4- and 5-year-old plantations of all species. A significant effect on concentrations of total SOC, TKN and TP were observed due to plantation age, species and soil depth. However, corresponding concentrations (SOC, TKN and TP) were substantially lower at spoil profile of 10–20 cm. In comparison, plantation of *A. lebbeck* showed greater SOC and nutrient concentrations followed by *D. strictus*, *A. procera* and *T. grandis*, respectively. Therefore, present study clearly indicates attributing qualities of plantation towards improving redeveloping soil of mine spoil varied with species.

Keywords: coal mine spoil; coal mine rehabilitation; soil restoration

Introduction

Mining of coal resources either by opencast or by underground process has serious insinuation for environmental security if proper management strategies are not adopted (Singh et al. 1995). Expansion of industrialization for human development needs massive energy generation, for which huge quantity of coal is extracted through mining, causing extensive landscape destruction (Bradshaw 2000; Singh et al. 2006a).

Mine spoils originated from opencast mining process, which removes surface earth, peeling it over un-mined land and forming chains of external dumps, recalled as overburden or mine spoil. In general, these spoils are not suitable for both plant and microbial growth because of low organic matter, and other unfavorable physico-chemical characteristics, especially insufficient amount of essential nutrients (N and P) (Singh et al. 1995; Singh et al. 1999; Singh et al. 2004a, b). Due to this situation, recovery of such degraded ecosystems into original state needs a carefully scientific approach to manage the problem. The recovery by natural succession is a very slow process; it depends on time and space and is influenced by geographical and climatic factors and ecological condition of the problem site. However, it can be accelerated by planting some desirable species that can develop a nutrient circuit in the soil for self-sustaining community through colonization of native plants in the long term and avoiding soil erosion by plant cover in short term (Singh et al. 1995; Yusuf et al. 2004).

According to Singh & Singh (1999), a desired species for planting on mine spoils should possess the abilities: (i) to grow on poor and dry soils, (ii) to develop the vegetation cover in short time and to accumulate biomass rapidly, (iii) to bind soil for arresting soil erosion and checking nutrient loss, and (iv) to improve the soil organic matter status and soil microbial biomass, thereby enhancing the supply of plant available nutrients. In addition, the species should be of economic importance.

Restoration success depends on the augmentation of biological activity of the surface soil horizons in the long term; thus, the primary approach to revegetation is to raise the levels of essential nutrients (C, N and P) in the soil and to control soil erosion by plant cover. N and P are two major limiting nutrients in various newly established coal sites (Bradshaw 2000; Singh et al. 2004a, b), which limit the establishment and proper growth of vegetation. Therefore, the objective of the present study was to investigate the influence of planting species on essential nutrients of coal mine spoil in redeveloping stage.

Materials and methods

Description of study site and plantation stands

The study was conducted on four selected plantations in the east section of Jayant Block, which is located in the northeastern part

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Biography: A. N. Singh (1970–), *Corresponding author, male, Lecturer in Department of Botany, Panjab University Chandigarh-160014, India (E-mail: dranand1212@gmail.com; dranand1267@yahoo.co.in)
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of the Singrauli Coalfield in the Sidhi district, Madhya Pradesh, India (Lat. 24°6'45"–24°11'15"N, Long. 82°36'40"–82°41'15"E, and elevation 280–519 m above mean sea level). The selected plantation species are indigenous and possess varied ecological characteristics such as short stature leguminous trees (*Albizia lebbeck* (L.) Benth.) and *Albizia procera* (Roxb. Benth.), slow growing timber tree (*Tectona grandis* L. f.) and fast growing woody grass (*Dendrocalamus strictus* (Roxb.) Nees.). The four species showed contrasting pattern in vegetational characteristics on coal mine spoil. Some general stand characteristics such as stocking density, stand basal cover, canopy cover and some vegetational characteristics like total tree layer biomass, leaf litter fall and tree layer net primary production (NPP) are given in Table 1.

Table 1. General characteristics of 5-year-old plantations of certain native woody species on coal mine spoil. (Values are means ± 1 SE.)

Species	Stand density (individual·ha^{-1})	Stand basal area (m^2·ha^{-1})	Canopy cover (m^2)	Height (m)	Basal diameter (cm)	Tree layer biomass (t ha^{-1})	Leaf litter fall (kg·ha^{-1}·a^{-1})	Tree layer net primary production (t·ha^{-1}·a^{-1})
A. lebbeck	2187 ± 14	13.79 ± 0.4	9.88 ± 4.40	4.02 ± 0.05	8.96 ± 0.10	51.81 ± 0.64	8.14 ± 0.06	23.86 ± 0.62
A. procera	2208 ± 9	14.98 ±1.36	4.46 ± 1.22	3.71 ± 0.23	9.29 ± 0.25	32.86 ± 2.20	7.94 ± 0.12	19.29 ± 1.09
T. grandis	1778 ± 68	5.81 ± 0.58	2.11 ± 0.82	2.89 ± 0.11	6.45 ± 0.15	7.44 ± 0.41	2.39 ± 0.10	4.76 ± 0.39
D. strictus	2029 ± 29	2.58 ± 0.3	4.22 ± 1.82	5.24 ± 0.18	4.12 ± 0.17	74.68 ± 2.41	11.00 ± 0.41	32.04 ± 2.91

The climate of the area is tropical monsoonal, therefore whole year is divisible into a mild winter (November–February), a hot summer (April–June) and a warm rainy season (July–September). Data collected at a meteorological station present on the site revealed that the mean monthly minimum temperature within the annual cycle ranges from 6–28ºC and mean monthly maximum from 20–40ºC. The annual rainfall averages 1 069 mm, of which about 90% occurs during late June to early September (Singh et al. 1995). Physico-chemical characteristics of fresh mine spoil indicated soil had neutral pH, high bulk density, low water holding capacity and poor soil nutrients. In comparison, soil collected from under planted species also was depicted neutral pH (6.58–7.22), but slightly lower bulk density (1.60–1.64 g·cm^{-3}) and higher water holding capacity (253.2–286.5 g·kg^{-1}) (Singh et al. 2004a).

All the plantations were raised in the month of July–August by planting nursery-raised seedlings in previously dug pits of 40 cm × 40 cm × 40 cm in size at a spacing of 2 m × 2 m. Plantations of *A. lebbeck* and *A. procera* were raised in 1990 by planting 7- to 8-month-old nursery raised seedlings on 1.5-ha area of mine spoil at east side. Plantation of *T. grandis* was also raised in 1990 by planting 6- to 8-month-old nursery-raised seedlings on 0.5-ha western section of mine spoil dump, while *D. strictus* plantation was raised in 1991 by planting 8-month-old nursery-raised seedlings on eastern section of mine spoil dump covering area of 0.5 ha.

For sampling, three permanent plots were established for each species. The size of the sample plots was 25 m × 25 m for *A. lebbeck* and *A. procera*, and 15 m × 15 m for *T. grandis* and *D. strictus*. The stocking density at the time of planting was 2 500 individual·ha^{-1} for all species. However, at the time of study, about 71%–88% individuals were survived in the plantation sites (Table 1).

Sample collection and analyses

Soil samples were collected randomly from each of the three permanent plots of each species using 15 cm × 15 cm × 10 cm monoliths for soil depth of 0–20 cm at 10-cm interval in September 1994, and 1995. Each time, six random soil samples within a plot were taken and thoroughly mixed to yield one composite sample per plot separately for each soil depth; this yielded six samples for each plantation on each sampling date. Large pieces of plant materials were removed and the field-moist soil was air dried, sieved through a 2-mm-mesh screen, and then used for the analysis of soil organic C, Kjeldahl N and total P. Soil organic C was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Allen et al. 1986). Kjeldahl N was determined by microkjeldahl method (Jackson 1958), and samples were analyzed for P by a phosphomolybdic acid blue color method (Jackson 1958) after triple acid digestion.

Statistical analyses

To observe effect of age, species and spoil depth the data were subjected to analyze for analysis of variance (ANOVA) through statistical software package (SPSS, Inc. 2001).

Results and discussion

Soil organic carbon

Soil organic carbon (SOC) concentration ranged from 2.30 to 7.25 g·kg^{-1} at 0–10 cm soil depth in 4- to 5-year-old plantations on mine spoil, with the maximum in *A. lebbeck* (7.25 g·kg^{-1}) and the minimum in *T. grandis* (2.30 g·kg^{-1}) plantation (Fig. 1 a-d). Corresponding values were significantly lower at 10–20 cm spoil depth (Fig. 1 a-d) in all plantations. However, ANOVA indicated significant differences due to plantation age, soil depth and tree species, but their interactions (age × depth, species × depth, and species × depth × age) were non-significant except one interaction between species × age (Table 2).

SOC is important for the sustainability of vegetation (Singh et al. 2006b). In this study, SOC in all plantations followed the order: *A. lebbeck* >*D. strictus* >*A. procera* > *T. grandis*. Natural resources available to restoration at disturbed site are climate, soil, water and biota. Climate, vegetation and soil are fundamentally interrelated and determine the type of ecosystem developing in particular area. The soil type determines the type of vegetation but its characteristics are changed by the vegetation through the

addition of plant litter to the soil. Thus, plant litter derived from above ground (leaf fall, branch fall, etc.) and below ground (dead roots) parts is source of soil organic matter formation in the upper layer of soil horizon by microbial breakdown (Singh et al. 1995; Frouz et al. 2001). Therefore, SOC is a function of quantity of dry matter deposited as litter fall on the ground surface of mine spoil (Singh 1999; Singh et al. 2006a). Evidently, high quantity of litter fall and its relatively slow decomposition as reported in all species may lead to build-up soil organic matter over the long period and provides the benefits of mulching (Singh et al. 1999; Singh et al. 2004b). According to Giardina et al. (2001), high quality litter leads to form high quality organic C and N in the mineral soil. In conformity with this, Resh et al. (2002) documented that certain leguminous species have ability to produce high quality of litter especially rich in C and N concentration. In this study, soil C and N increased with plantation age in all species, however highest concentration was found in the soil layer of *A. lebbeck* (a legume) followed by *D. strictus*, *A. procera* and *T. grandis* plantation.

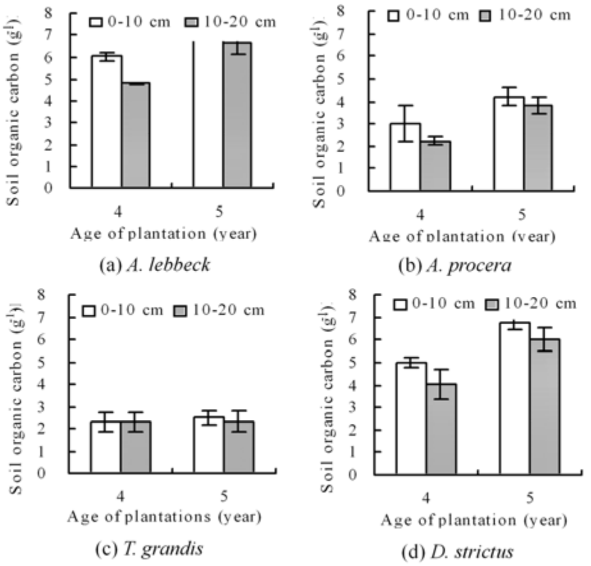

Fig. 1 Soil organic carbon (SOC) under plantations of certain woody species (a-d) in redeveloping soil of mine spoils. (Bars are ± 1 SD.)

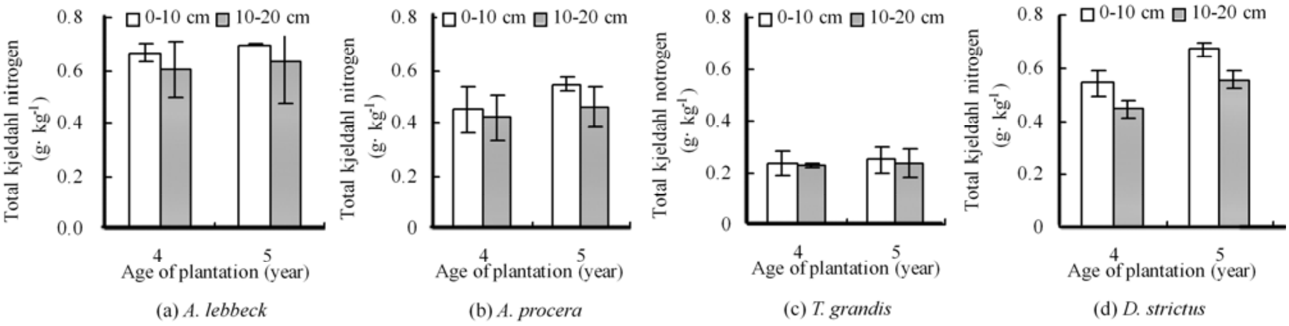

Fig. 2 Total Kjeldahl nitrogen (TKN) under plantations of certain woody species (a-d) in redeveloping soil of mine spoils. (Bars are ± 1 SD.)

Table 2. ANOVA results for total organic carbon, nitrogen and phosphorus concentrations in redeveloping soil of mine spoil under woody plantations of native species

Source	*df*	Carbon	Nitrogen	Phosphorus
Age	1	101.317***	10.814*	4.478*
Species	3	215.100***	103.368***	4.281**
Depth	1	24.278***	12.552*	5.622*
Species × Age	3	10.034***	1.990 NS	0.135 NS
Species × Depth	3	2.303 NS	1.182 NS	0.022 NS
Age × Depth	1	1.094 NS	0.234 NS	0.002 NS
Species × Depth × Age	3	0.448 NS	0.197 NS	0.285 NS
Residual	32			
Total	48			

Notes: *, ** and *** present significant at $P < 0.05$, < 0.01 and < 0.001 probability levels, respectively. NS denotes non-significant at $P < 0.05$.

Total Kjeldahl nitrogen

Total Kjeldahl nitrogen (TKN) concentrations in all plantations of 4- to 5-year-old age varied from 0.24 to 0.70 g·kg^{-1} at the soil depth of 0–10 cm, with the maximum in *A. lebbeck* (0.70 g·kg^{-1}) followed by *D. strictus* (0.67 g·kg^{-1}) and *A. procera* (0.46 g·kg^{-1}) and the minimum in *T. grandis* (0.24 g·kg^{-1}) plantation (Fig. 2 a-d). Similar to SOC, TKN concentration was significantly lower at spoil depth of 10–20 cm in all species (Fig. 2 a-d). ANOVA revealed significant differences due to plantation age, soil depth, and tree species; while their interaction (age × depth, species × depth, and species × depth × age) were not significant except species × age (Table 2).

In this study, highest soil N was found in *A. lebbeck* plantations, an N-fixing plant and lowest in *T. grandis,* a non-leguminous tree. Whereas, *A. procera* plantation, another N-fixer, was not much effective in improving soil N status because leaf litter of *A. procera* (2.12 mg·g^{-1}·d^{-1} mean relative decomposition rate) decomposes slowly as compared to *A. lebbeck* (2.42 mg·g^{-1}·d^{-1} mean relative decomposition rate) (Singh et al. 2004b), indicating that all N-fixing plants may not be equally efficient in raising soil N levels (Singh et al. 2006b). However, the soil under 5-year-old plantations at soil depth of 0–10 and 10–20 cm had 4.5% and 5.0% greater N in *A. lebbeck*, 22.2% and 9.5% in *A. procera*, 4.2% and 0 in *T. grandis* and 34.0% and

24.0% in *D. strictus* than those under 4-year-old plantation of all species. Perhaps, both leguminous species differed in foliage biomass and their N concentration in 4- to 5-year-old plantation, and belowground contribution to tree layer biomass was higher in *A. procera* ($\bar{x}$ = 40%, averaged of 4- and 5-year old) than in *A. lebbeck* ($\bar{x}$ = 26%), (Singh et al. 2004b). Thus, the relative development of aboveground and belowground structure on mine spoil and the soil properties were species-specific (Sands and Mulligan 1990). Between the non-leguminous species (*D. strictus* and *T. grandis*), *D. strictus* is fast growing, perennial woody tropical grass, produced very high level of biomass (74.68 $t{\cdot}ha^{-1}$) and NPP (32.04 $t{\cdot}ha{\cdot}a^{-1}$) at 5-year old that provided high inputs of litter fall (11.00 $t{\cdot}ha^{-1}$), which reflected increasing concentrations of total N in both soil layers (Singh et al. 1999), while *T. grandis* did not improve soil N due to poor quality of its litter quality (0.67% N and 0.11% P) and low biomass productivity (4.76 $t{\cdot}ha^{-1}{\cdot}a^{-1}$), (Singh 1999; Singh et al. 2004c).

Total phosphorus

In this study, total P among the four plantation species ranged from 0.14–0.19 $g{\cdot}kg^{-1}$ at 0–10 cm and 0.12–0.17 $g{\cdot}kg^{-1}$ at spoil depth of 10–20 cm, respectively in 4- to 5-year-old plantations (Fig. 3 a-d). Although effects of species, plantation age and spoil depth were significant factors affecting the amount of total P in the soil, but their interactions (species × age, species × depth, age × depth and species × depth × age) were totally non-significant (Table 2). Phosphorus is an essential element for plant growth but deficient in colliery spoil sites (Bloomfield et al. 1982). It primarily accumulates in soil as a result of microbial activity, and becomes available through mineralization to inorganic P (Dalal 1977). Phosphorus moves slowly through soils (Blair 1976) and availability in soils may result from variable microbial activity (Clark et al. 1981). The soil under 5-year-old plantation had 11.8% greater P in *A. lebbeck*, 17.3% in *A. procera*, 12.5% in *T. grandis* and 0.0% in *D. strictus* than those under 4-year-old plantations of all species, indicating that the effect of plant species on P is species-specific and it needs more intensive study in future.

According to Wood et al. (1984), biological activity controls the P retention in the surface soil while geo-chemical activity controls P retention in the lower soil horizons. In this favour, Spears et al. (2001) reported that biological activity was more prevalent in the surface soil horizons of leguminous species than non-legumes. Perhaps due to this reason, both legumes (*A. lebbeck* and *A. procera*) reflected a substantial contribution to raising P levels in the soil. However, many researchers have found it is difficult to correlate with mine spoil P concentrations with vegetation response (Roberts et al. 1988; Van Aarde et al. 1998; Mercuri et al. 2006). Evidently, in this study, there was a significant age-related trend in total soil P; but available-P (PO_4-Pi) was reported neither age- nor species-related (Singh 1999; Singh et al. 1999; Singh et al. 2004a), confirming the independent behaviour of P.

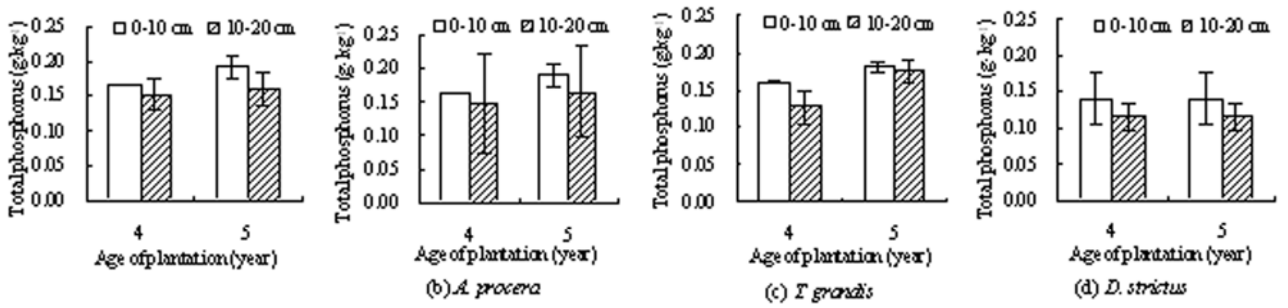

Fig. 3 Total phosphorus (TP) under plantations of certain woody species (a-d) in redeveloping soil of mine spoils. (Bars are ± 1 SD.)

Conclusions

In this study, the highest soil organic C and total N values were found at both soil depths (0–10 and 10–20 cm) in *A. lebbeck* plantation followed by *D. strictus*, *A. procera* and *T. grandis* plantations, respectively. Highest total P levels were found in the plantations of *A. lebbeck* and *A. procera* (N-fixing plant, legume), followed by *T. grandis* and *D. strictus* (non-fixing N plant, non-legume) plantations. Corresponding concentrations of soil nutrients in the present study were much lower as compared to the data available for nearby native forest (organic C 4.7–20.0 $g{\cdot}kg^{-1}$, total N 0.5–1.6 $g{\cdot}kg^{-1}$ and total P 0.21–0.32 $g{\cdot}kg^{-1}$) (Singh et al. 1991). In non-leguminous species, *T. grandis* was not as effective as *D. strictus*, whereas *A. procera* was not effective as *A. lebbeck* in legumes due to the lower growth and less accumulating efficiency in biomass and net primary production. In conclusion, a continued increase in C, N and P concentrations at 0–10 and 10–20 cm spoil depth in all plantations with plantation age indicated a progressive improvement in soil rehabilitation. These plantations are in developing stage and it will take time to reach soil nutrient levels comparable to nearby natural forests.

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